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How would ambitious CO_2 prices affect air transport?

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Abstract

In the last years, scientists as well as political activists proposed the introduction of ambitious prices for all CO_2 emitting sectors, including aviation. Suggested prices range from about 45 to 350 € per ton of CO_2. Such prices are considered an indispensable element of a strategy aiming at stabilizing the global temperature increase well under 2.0 degrees Celsius (Paris objective). For comparison: As of May 2020, the price for European Emission Allowances in the European Emission Trading Scheme was about 20 €/t CO_2. European Air Transport has been participating in this scheme on a mandatory basis since 2012.

How would such ambitious CO_2 prices affect air transport? How likely are a significant increase in airfares and a corresponding decrease in demand? This paper investigates the potential impacts of high CO_2 prices on airfares and growth in aviation. For this, we analyze the relevant literature and conduct some model-based estimations. In addition, we provide a rough estimate of the economic impacts in case not only CO_2 but all climate relevant species from aviation (NO_x, SO_x, H_2O, aerosols, contrails and contrail cirrus) would become subject to emission pricing.

Keywords: Aviation; climate relevant emissions; CO_2 pricing

1. Background

In the last years, scientists as well as political activists proposed the introduction of ambitious prices for all CO_2 emitting sectors, including aviation. Such prices are considered an indispensable element of a strategy stabilizing the global temperature increase well under 2 degrees Celsius (Paris objective). For instance, the World Bank Report of the High-Level Commission (2017) suggests a price of 44 to 88 € per ton of CO_2 and Edenhofer/Flachsland (2018) conclude 130 to 350 €/t CO_2 are necessary to achieve the Paris objective. The climate activists 'Fridays for Future (FFF)' propose carbon prices which mirror the costs of climate change for the actual and upcoming generations (FFF, 2019). According to a recent study of the German Environmental Agency (Umweltbundesamt, 2019), a price range of 180 to 360 €/t CO_2 could mirror these costs. For comparison: As of May 2020, the price for European Emission Allowances in the European Emission Trading Scheme (EU ETS) was about 20 € per ton of CO_2 (EEX, 2020). Moreover, a large share of these allowances is issued for free. European Air Transport has been participating in this trading scheme on a mandatory basis since 2012.

This paper investigates potential impacts of such ambitious CO_2 prices on airfares and growth in aviation. More specifically, we analyze the relevant literature and conduct some model-based estimations for pre-selected sample routes. In addition, we provide a rough estimate of the economic impacts if not only CO_2, but all climate relevant species from aviation (NO_x, SO_x, H_2O, aerosols, contrails and contrail cirrus) were subject to emission pricing. Alternative ways to reduce the sector's climate impact, such as CO_2 standards (e.g., Eide et al., 2014) or the use of alternative fuels (e.g., Chiaramonti, 2019), are not tackled in this paper.

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2. Literature review

For air transport, studies on the impact of CO_2 prices of or above 180 €/t can hardly be found in literature. In fact, predominantly prices in the range of 10 to 40 €/t CO_2 emissions have been investigated so far. According to Scheelhaase et al. (2016), e. g., assuming a full pass-through of the additional costs to the passengers, airfares would increase by 1 % on long-haul operations if a carbon price of 10 €/t was introduced. Sgouridis et al. (2011) modeled the impacts of a carbon price of 200 USD/t. This leads to an 8 per cent reduction of CO_2 emissions, compared to a business-as-usual development. The main reasons for this are technology driven efficiency gains and a moderately decreased demand for air services.

Air transport contributes to climate change not only by emitting CO_2, but also NO_x, SO_x, H_2O, aerosols, contrails and contrail cirrus. Lee et al. (2009) estimated aviation's CO_2 and non-CO_2 contribution to total radiative forcing to be about 4.9 % for the year 2005 where the share of the so-called non-CO_2 species was 3.3 %. More recent estimations are not yet available to date. A price on aviation's full climate impact (CO_2 plus non-CO_2 species) would certainly lead to much larger effects since a larger amount of climate relevant emissions would be targeted. It is, though, not straightforward to quantify these effects. As the climate impact of the so-called non-CO_2 emissions depends on the operational environment (altitude of the flight, geographical location, time of day, actual weather situation etc.), there is no linear relationship between CO_2 and non-CO_2 impacts (Dahlmann et al. (2016), Fichter et al. (2005)). In addition, large scientific uncertainties concerning the climate impact of some non-CO_2 species still exist.

Our literature review shows initial studies on the economic impact of limiting the full climate impacts from aviation. A first in-depth analysis of such impacts was conducted in the AviClim research project (see Scheelhaase et al. (2016) and Scheelhaase (2019)). The interdisciplinary project investigated the feasibility and economic effects of including aviation's full climate impact, i.e., both long-lived CO_2 and short-lived non-CO_2 effects, in international protocols for climate. Short-lived non-CO_2 effects of aviation are mainly NO_X, H_2O, SO_x, aerosols, contrails and contrail cirrus. Further studies have been conducted by Lührs et al. (2018) or Grewe et al. (2017). However, these studies focused on atmospheric science related questions.

Based on AviClim modelling results, Scheelhaase (2019) investigated the cost impacts of addressing aviation's full climate impact by the European Emission Trading Scheme (EU ETS) which currently only limits the CO_2 emissions of air transport. In principle, this is possible by 'translating' the climate impact of the non-CO_2 species into equivalent CO_2. Scheelhaase et al. (2016) provides a detailed description of the method used for these calculations.

Table 1 presents cost estimations for complying with an EU ETS limiting aviation's full climate impact. These estimations have been conducted for selected flights under the assumption of a CO_2 equivalent price of 8 €/t. For comparison, in this paper we have added a back-of-the-envelope calculation for a CO_2 equivalent price of 180 €/t. For these calculations, a full and straight pass-through of the additional costs from the ETS to the costumers has been assumed. In reality, there will be numerous possibilities for the airlines to differentiate their pass-through strategies between costumer groups, depending on their empirical price elasticities of demand.

As expected, costs for complying with an EU ETS for regulating the full climate impact of aviation are much larger than for a CO_2-only regime. This is because the amount of CO_2 equivalent regulated is significantly larger under a system limiting aviation's full climate impact. Also, the price per ton of CO_2 equivalent assumed determines average costs per flight segment and passenger. Furthermore, the flight length is a crucial factor for the cost impact induced by the regulatory measure investigated. As Table 1 shows, the largest cost effects have been calculated for long-haul flight tickets while short-hauls will only have to bear a relatively small financial burden. In absolute terms, for instance, additional costs for the one-way ticket Prague (PRG) – New York (JFK) would reach 242 € (CO_2 + non-CO_2 regime, 180 €/ t CO_2 equivalent) and 57 € (CO_2 regime, 180 €/t CO_2), whereas a short- or medium-haul flight ticket, such as Barcelona (BCN) – Dusseldorf (DUS) or Dublin (DUB) – Memmingen (FMM) would be subject to cost increases by 29 € (CO_2 + non-CO_2 regime) and 7 € (CO_2 regime) and 23 € (CO_2 + non-CO_2 regime) and 6 € (CO_2 regime), respectively. The main reason for these cost differences between long- and short-hauls is that NO_x emitted on high altitudes (i. e. cruise levels) has an increased climate impact (Lee et al. (2010) and Lee et al. (2009)). Consequently, long-haul operations cause relatively larger amounts of non-CO_2 emissions than short- and medium-haul flights. This leads to relatively higher costs per passenger and ticket for long-haul flights than for shorter operations.

Table 1: Cost for complying with the EU ETS per passenger and flight segment in the year 2020

Departure	Destination	Airline	Seats	Load factor	Cost per passenger per flight segment in €			
					CO_2 + Non-CO_2 regime (8 €)	CO_2 + Non-CO_2 regime (180 €)	CO_2 regime (8 €)	CO_2 regime (180 €)
Amsterdam	Paris	KLM	132	0.81	0.32	7.20	0.21	4.72
Cologne	Berlin	Germanwings	189	0.76	0.25	5.62	0.15	3.37
Barcelona	Düsseldorf	Germanwings	144	0.76	1.29	29.00	0.32	7.2
Dublin	Memmingen	Ryanair	189	0.97	1.04	23.4	0.28	6.3
Munich	Mallorca	Lufthansa	144	0.79	1.66	37.35	0.44	9.9
Düsseldorf	Dubai	Emirates	278	0.75	7.80	175.5	1.92	43.2
Munich	Miami	Lufthansa	221	0.79	11.79	265.27	3.55	79.87
Paris	Los Angeles	Air France	280	0.86	15.80	355.50	3.54	79.65
Prague	New York	Delta	225	0.86	10.76	242.10	2.55	57.37

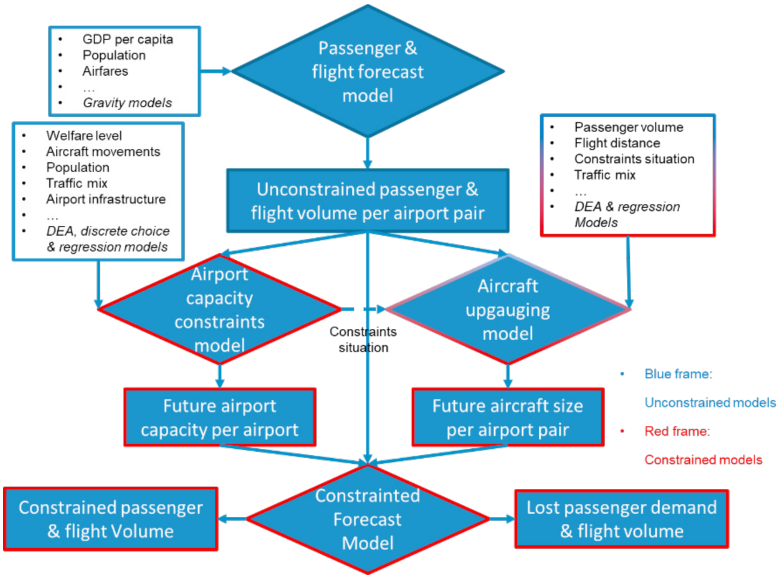
Source: DLR modelling results, based on Scheelhaase et al. (2016). 8 € and 180 €/t CO_2 equivalent have been assumed. Belly freight has not been taken into account for the selected flights. Load factor data was taken from the airlines' websites.

The use of synthetic kerosene (e-fuels) could also contribute to a sustainable air transport system since these fuels reduce aviation's climate-relevant emissions. Moreover, as blending with conventional kerosene is possible at least up to certain drop-in levels (e.g., Schmidt et al., 2016), synthetic fuels have the advantage that existing infrastructure, vehicles and engines can be further used. This could allow for a relatively smooth and step-wise system transition. However, synthetic fuels are much more costly than conventional fuels today. And these fuels are expected to remain more expensive in the future, even though on-going research and development will lead to advanced production technologies and economies of scale in the next decades: For 2016, DLR estimated costs for synthetic kerosene of about 2.26 € per liter, compared to circa 0.5 € for conventional fuel (Albrecht, 2017). At today's technological knowledge, Ludwig-Bölkow-Systemtechnik (LBST) estimated e-fuel costs of about 3,245 €/t (Schmidt et al., 2018). Due to advanced production technologies and economies of scale in the next three decades, LBST expects significantly lower production costs for synthetic kerosene. This could lead to a price of about 1,352 €/t in the year 2050. However, this would still be almost twice the price as for conventional fuel today. Against this background, synthetic fuels in aviation would need supportive regulatory measures, such as mandatory blending quotas, to become a competitive option, even under a CO_2-Emissions Trading Scheme or other CO_2-pricing measures.

3. Methodological Approach

This section provides a brief overview of the model which generates the forecast scenarios for the following section, while Gelhausen et al. (2020) contains a full model documentation. Figure 1 illustrates the general model approach. In a first step, the unconstrained passenger and flight forecast is established. Passenger and flight volume per airport pair is modelled by a gravity model with a number of explanatory variables like GDP per capita, population and airfares development. As a result, we obtain a so-called unconstrained passenger and flight volume forecasts for each airport pair. On this basis, airport capacity constraints and related aircraft upgauging, i.e. the use of larger aircraft, is implemented. The airport capacity constraints model contains a model to calculate current airport capacity for each airport by data envelopment analysis (DEA) and regression models and, on the basis of discrete choice theory, a model that estimates the probability for airport capacity expansion, in case it is not sufficient to handle the forecast demand. Important explanatory variables for those two models are the welfare level and the number of the people living around the airport, the number of aircraft movements of an airport, traffic mix and the current airport infrastructure. The aircraft upgauging model belongs to the unconstrained as well as constrained models (box with blue and red edges), as upgauging not only depends on the level of airport capacity constraints, but also various other factors, such as passenger demand volume or flight distance. The model is implemented by DEA and regression models and contains factors such as passenger volume, flight distance, the constraints situation at airports and traffic mix. Forecast result is the average number of passengers per flight ("aircraft size") on each airport pair. Combining the future airport capacity and aircraft size per airport pair with the unconstrained passenger numbers leads to the constrained forecast model. Forecast results are the constrained passenger and flight volume as well as the lost passenger demand and flight volume because of limited airport capacity.

Figure 1: Overview of the forecast model

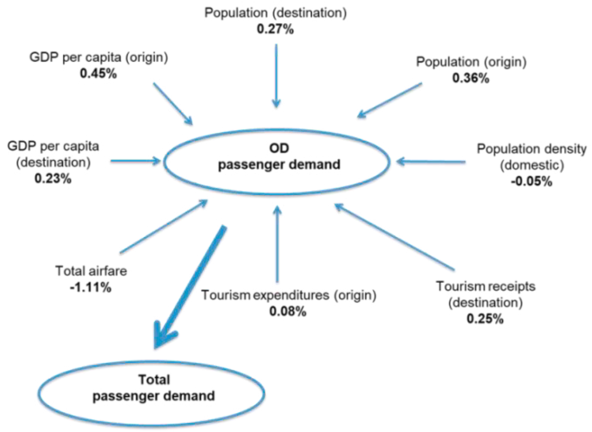


Source: Wilken et al. (2020).

Demand elasticities are a fundamental element for the demand forecast. Figure 2 illustrates the impact of the major input factors on OD passenger demand volume which underlie the forecasts. For example, if total airfares (incl. taxes and fees) rise by 1%, OD passenger volume is modelled to decline by 1.11%. On the other hand, if GDP per capita increases in the origin country by 1%, then OD passenger demand will rise by 0.45%. GDP is broken down into four parts: GDP per capita for the origin and destination country and population for origin and destination country. However, estimated total GDP elasticity is about 1.31 and thus OD passenger demand is elastic to GDP variations. This more or less conforms to typical results (e.g. IATA, 2007; Gallet and Doucouliagos, 2014), however, we use an airfare variable and further variables like distance, tourism receipts and expenditures etc. to account for different market segments (Gelhausen et al., 2020).

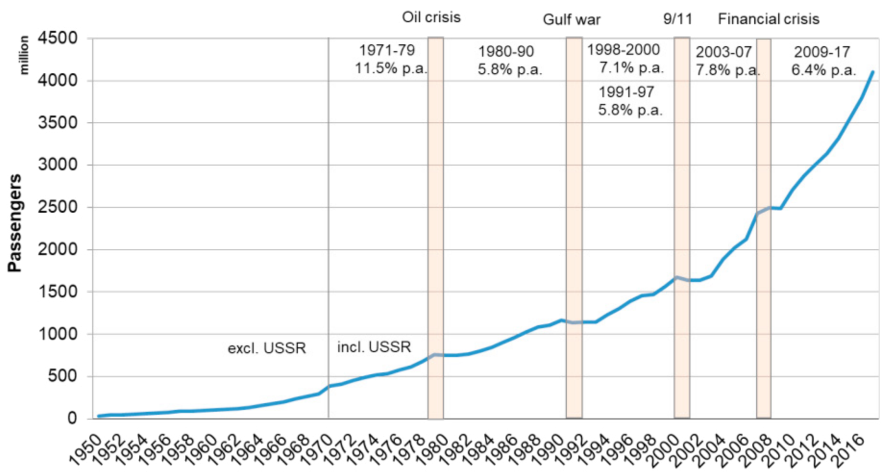
As the model is suited for long-term development of air transport, we do not account for short- and medium-term fluctuations which may last over few years such as potential short-term effects of the COVID-19 crisis, which go far beyond GDP effects alone. However, medium to long-term effects are typically reflected in long-run GDP development, which is a major input variable of the model. Figure 3 illustrates the long-term development of global air transport in the light of periodic major crisis, which used to happen around every ten years. After previous crises, global air transport development returned back to the original growth path within a few months or years.

Figure 2: Major elasticities of the unconstrained passenger demand volume model



Source: Gelhausen et al. (2020).

Figure 3: Development of global air traffic since 1950



Source: Gelhausen et al. (2020).

While we acknowledge that the short-term decline caused by Covid-19 is unprecedented in its extent, we do not expect a structural interruption caused by COVID-19 in the long-term, but a continuation of trends that have been already present before. For example, global growth may become more and more shaped by emerging countries especially in Asia and the Middle East, and less by Europe and North America (Gelhausen et al., 2020), reflecting rising income in the former countries and increasing capacity constraints especially in Europe.

4. Results

This section presents our model-based calculations which illustrate how passenger demand volume would change as a result of a CO_2 price of 180 €/t CO_2. For two reasons, a production cost increase does not automatically lead to a reduction in airline growth and/or profits. First, any demand reaction to higher airfares will depend on the actual price elasticities of demand in the market, and on the cost pass-through rate. And second, a price on CO_2 emissions will only lead to higher production costs if the airlines under the scheme are not able to fully mitigate these emissions, which may become a reasonable option if alternative fuels become available in the medium to long run.

As already described, we estimated a price elasticity of -1.11, i.e. an increase of 1% of the airfare (including taxes and fees) leads to a demand volume reduction of 1.11% (Gelhausen et al., 2020). Furthermore, we assume in the "Base Case" scenario a seat load factor of 90% and that a CO_2 price would be fully passed on the air passengers. Assuming a high seat load factor dampens the effect of the CO_2 price on passenger demand volume, as CO_2 emissions of an airplane are almost independent from the number of passengers transported. However, passing the CO_2 fee fully on the air passenger leads to a maximum demand reduction. Variations of these two assumptions have a more or less proportional effect on the calculation results. Nevertheless, two additional scenarios are created to illustrate the effects of a partial pass of the CO_2 price on air passengers and varying seat load factors:

- "Partial Pass-through of CO_2 Tax": In this scenario, we assume that only 50% of the CO_2 tax is passed through to the air passenger.
- "Low Seat Load Factor": In this scenario, we assume a seat load factor of only 60%, i.e. one third less to the "Base Case" scenario and a full pass-through of the CO_2 tax to the air passenger.

Table 2: Scenario results "Base Case" for the sample routes (90% load factor, CO_2 price fully passed-through to the air passenger

Departure	**Arrival**	**Average CO_2 emissions/PAX**	**Average air fare (in Euro)**	**Additional CO_2 cost per ticket**	**Passenger demand decrease**
Amsterdam	Paris	0.06 tons	93.2 €	10.27 €	-11.0%
Cologne	Berlin	0.06 tons	166.05 €	10.84 €	-6.8%
Dublin	Memmingen	0.10 tons	110.28 €	18.34 €	-15.7%
Munich	Palma de Mallorca	0.11 tons	127.18 €	19.26 €	-14.5%
Dusseldorf	Dubai	0.48 tons	418.48 €	85.83 €	-18.7%
Paris	Los Angeles	0.86 tons	836.72 €	154.09 €	-17.1%
Prague	New York	0.69 tons	611.13 €	123.81 €	-18.5%
Berlin	Palma de Mallorca	0.14 tons	117.33 €	25.05 €	-19.3%
Frankfurt	Auckland via Dubai	2.44 tons	1000.14 €	438.99 €	-33.2%

Source: Own modelling results. Data from 2019.

As Table 2 shows, the largest demand reduction can be found on the route from Frankfurt to Auckland via Dubai. Here, CO_2 emissions per passenger are relatively large compared to ticket price, leading to a demand decrease of 33%. In contrast, the lowest demand decline applies to the Cologne – Berlin route, as there are rather low CO_2 emissions per passengers in conjunction with a relatively high ticket price. The CO_2 emissions per passengers are almost identical on the Amsterdam – Paris route, but as ticket prices are much lower, the relative demand decline would almost double. Therefore, routes with very competitive airfares, long hauls and flights operated by inefficient aircraft in terms of CO_2 emissions would be much more affected by the introduction of a CO_2 price than short-hauls with higher fare levels and efficient aircraft. However, for the scenario calculations, we assume that there are no technological or organizational innovations by the airlines which reduce average CO_2 emissions per passenger. Of course, this is a realistic assumption only in the short-term, but not in the medium- and long-term. Nevertheless, the assumptions chosen tend to overestimate the true long-term effects of a CO_2 tax.

Table 3: Scenario results “Partial Pass-through of CO_2 Tax” for the sample routes (90% load factor, CO_2 price 50% passed-through to the air passenger

Departure	Arrival	Average CO_2 emissions/PAX	Average airfare (in Euro)	Additional CO_2 cost per ticket	Passenger demand decrease
Amsterdam	Paris	0.06 tons	93.20 €	5.14 €	-5.78%
Cologne	Berlin	0.06 tons	166.05 €	5.42 €	-3.50%
Dublin	Memmingen	0.10 tons	110.28 €	9.17 €	-8.49%
Munich	Palma de Mallorca	0.11 tons	127.18 €	9.63 €	-7.78%
Dusseldorf	Dubai	0.48 tons	418.48 €	42.92 €	-10.27%
Paris	Los Angeles	0.86 tons	836.72 €	77.05 €	-9.31%
Prague	New York	0.69 tons	611.13 €	61.91 €	-10.16%
Berlin	Palma de Mallorca	0.14 tons	117.33 €	12.53 €	-10.65%
Frankfurt	Auckland via Dubai	2.44 tons	1,000.14 €	219.50 €	-19.77%

Source: Own modelling results. Data from 2019.

As Table 3 shows, the passenger demand decrease is more or less only 50% compared to the “Base Case”, especially for routes where the additional CO_2 tax has little impact on demand. On routes with a large effect of the CO_2 tax, e.g. Frankfurt to Auckland or Dusseldorf to Dubai, the demand decrease would be reduced by less than 50% compared to the “Base Case”, which is a result of the isoelastic nature of the demand function. The relationship between relative price increase and demand reduction is roughly proportional only for small price changes, say below 10%.

Table 4: Scenario results “Low Seat Load Factor” for the sample routes (60% load factor, CO_2 price fully passed through to the air passenger

Departure	Arrival	Average CO_2 emissions/PAX	Average air fare (in Euro)	Additional airfare and CO_2 cost per ticket	Passenger demand decrease
Amsterdam	Paris	0.09 tons	93.20 €	62.01 €	-39.38%
Cologne	Berlin	0.09 tons	166.05 €	99.28 €	-36.49%
Dublin	Memmingen	0.15 tons	110.28 €	82.66 €	-32.54%
Munich	Palma de Mallorca	0.16 tons	127.18 €	92.48 €	-40.08%
Dusseldorf	Dubai	0.72 tons	418.48 €	337.98 €	-40.91%
Paris	Los Angeles	1.28 tons	836.72 €	649.49 €	-42.97%
Prague	New York	1.03 tons	611.13 €	491.28 €	-41.33%
Berlin	Palma de Mallorca	1.21 tons	117.33 €	96.24 €	-41.92%
Frankfurt	Auckland via Dubai	3.66 tons	1,000.14 €	1,158.55 €	-54.61%

Source: Own modelling results. Data from 2019.

Finally, Table 4 provides the effect of a seat load factor reduction from 90% to 60%, and a full pass-through of the CO_2 tax on the air passenger on demand. There are two effects: First, there is the additional CO_2 tax, as in the "Base Case" scenario. Second, airfares and CO_2 tax have to increase by 50% to account for the lower seat load factor. This results in a substantial increase in travel cost for the air passenger and leads to a demand reduction which significantly surpasses the second scenario, because of the double effect of the lower seat load factor: The lower seat load factor leads to a 50% increase of airfares and the CO_2 taxes, because a fixed amount of cost has to be distributed among a lower number of air passengers. While the additional costs in scenario 2 are rather modest, they are almost as high as the original airfare in scenario 3.

5. Conclusions and closing remarks

As shown for the case study routes, price increases and demand reduction can be significant, at least on long hauls where large amounts of CO_2 are emitted. However, such an ambitious CO_2 price will not automatically lead to the intended CO_2 reductions as airlines and passenger reactions are complex and partly opposing. For instance, this may be the case if the CO_2 price is only introduced in selected countries and aircraft are shifted to regions and routes where CO_2 has no price, or in cases where an environmental (CO_2) tax collides with an existing ETS. Therefore, to reach the highest possible CO_2 reduction effectiveness, political measures directly limiting the absolute CO_2 amount emitted (and indirectly influencing the CO_2 price) such as trading schemes, may be considered preferable. However, an emission trading scheme is only effective in terms of emissions reduction if the cap is set well below actual emissions levels which, at the end of the day, is a political decision. A consideration of non-CO_2 emissions, which are however more difficult to measure and hence to implement in an ETS, would further reduce the sector's climate impact.

References

Albrecht, F.G.; Maier, S.; Dietrich, R.-U. (2017): Power-to-X for the future fuels supply, Techno economic evaluation and system analysis, presentation held 18 Oct 2017, available online at: https://elib.dlr.de/116674/1/PraxisforumPtX_Dietrich_final4.pdf, retrieved 04 January, 2019.

Chiaramonti, D. (2019): Sustainable Aviation Fuels: the challenge of decarbonization. Energy Procedia, Vol. 158, pp. 1202-1207.

Dahlmann, K., Grewe, V., Frömming, C., Burkhardt, U. (2016) Can we reliably assess climate mitigation options for air traffic scenarios despite large uncertainties in atmospheric processes? Transportation Research Part D: Transport and Environment, Vol. 46, pp 40-55.

EEX (2020) Marktdaten Emissionen. https://www.eex.com/de/ (retrieved 22 May 2020).

Eide, J., de Sisternes, F.J., Herzog, H.J., Webster, M.D. (2014). CO_2 emission standards and investment in carbon capture. Energy Economics, Vol. 45, pp. 53-65.

Fichter, C., Marquart, S., Sausen, R., Lee, D.S. (2005) The impact of cruise altitude on contrails and related radiative forcing. Meteorologische Zeitschrift 14, pp 563-572.

Fridays for Future, FFF (2019); https://fridaysforfuture.de/forderungen/ (retrieved 3 May, 2019).

Gallet, C.A., Doucouliagos, H., (2014): The income elasticity of air travel: A meta-analysis. Annals of Tourism Research 49, pp. 141–155.

Gelhausen, M. C., Berster, P., Wilken, D. (2020): Airport capacity constraints and strategies for mitigation – A global perspective, Academic Press, London.

Grewe. V. et al. (2017): Mitigating the climate impact from aviation: achievements and results of the DLR WeCare project, Aerospace, 4/34 (2017), pp 1-50.

International Air Transport Association (IATA) (2007): Estimating Air Travel Demand Elasticities (prepared by InterVISTAS Consulting Inc.). Montreal.

Lee, D., Fahey, D., Forster, P., et al., (2009) Aviation and global climate change in the 21st century. Atmos. Environ. 43, pp 3520–3537.

Lee, D. S., G. Pitari, V. Grewe, K. Gierens, J. E. Penner, A. Petzold, M. J. Prather, U. Schumann, A. Bais, T. Berntsen, D. Lachetti, L. L. Lim, and R. Sausen (2010) Transport impacts on atmosphere and climate: Aviation. Atmospheric Environment 44, pp 4678 – 4734

Lührs, B., Niklaß, M., Frömming, C., Grewe, V., Gollnick, V. (2018): Cost Benefit Assessment of Climate and Weather Optimized Trajectories for Different North Atlantic Weather Patterns, 31st Congress of the International Council of the Aeronautical Sciences (ICAS), 9-14 September 2018, Belo Horizonte, Brazil.

Edenhofer, Ottmar, Flachsland, Christian (2018) Eckpunkte einer CO_2-Preisreform für Deutschland, Potsdam-Institut für Klimafolgenforschung (PIK)/Mercator Research Institute on Global Commons and Climate Change (MCC) gemeinnützige GmbH, MCC Working paper 1/2018, November 2018, Berlin.

Scheelhaase, Janina, Grimme, Wolfgang, Pabst, Holger, Bechtold, Jan (2016), EU Emissionshandel: Klimaschutz im Luftverkehr – Wie geht es weiter?, Wirtschaftsdienst, 11, pp 833-841.

Scheelhaase, J., Dahlmann, K., Jung, M., Keimel, H., Nieße, H., Sausen, R., Schaefer, M., Wolters, F. (2016): How to best address aviation's full climate impact from an economic policy point of view? – Main results from AviClim research project, in: Transportation Research, Part D, 45 (2016), pp 112-125.

Scheelhaase, J. (2019): How to regulate aviation's full climate impact as intended by the EU Council from 2020 onwards, in: Journal of Air Transport Management, 75 (2019), pp 68-74.

Schmidt, P.; Weindorf, W.; Roth, A.; Batteiger, V.; Riegel, F. (2016): Power-to-Liquids, Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel. Study on behalf of the German Environmental Agency, Dessau-Roßlau.

Schmidt, P. et al. (2018), Power-to-Liquids as Renewable Fuel Option for Aviation: A Review, Chemie Ingenieur Technik, Vol. 90, Nr. 1-2, pp 127-140, available online at: https://onlinelibrary.wiley.com/doi/full/10.1002/cite.201700129 [retrieved 17 January 2019].

Sgouridis, S. Bonnefoy, P. A., Hansman, R. J. (2011) Air transportation in a carbon constrained world: Long-term dynamics of policies and strategies for mitigating the carbon footprint of commercial aviation, Transportation Research Part A, 45, pp 1077-1091.

The World Bank (2017) Report of the High-Level Commission on Carbon Prices, Washington D. C.

Umweltbundesamt (2019) Methodenkonvention 3.0 zur Ermittlung von Umweltkosten – Kostensätze – Stand 02/2019, Dessau-Roßlau 2019.